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NOTES ON RESERVOIR SILTING AND SUSPENDED-LOAD MEASUREMENTS IN WASHINGTON

By

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INTRODUCTION

The storage reservoirs of the United States play a vital role in our industrial and agricultural war production. The domestic and industrial water supply of probably half of our war production centers comes from these reservoirs. One-third of the Nation's power comes from hydroelectric power dams, most of them dependent on storage reservoirs. Most of our irrigated agriculture, which produces many critically needed crops, depends on water storage. Most of our larger dams are now under military guard because their destruction would be a catastrophe, and their continuous function is vital to war production.

In many sections of the United States our storage reservoirs are being rapidly sabotaged by an enemy of our own making--silting that results mainly from accelerated soil erosion. We must maintain a vigilant guard against this insidious form of destruction just as surely as we must guard against damage by enemy agents.

For 8 years the Soil Conservation Service has been studying the effects of accelerated soil erosion on reservoir silting. This report is one of a series of summaries of existing data for different States and drainage basins compiled as a guide for engineers and conservationists who are charged with farm and watershed planning and construction of public and private storage developments.

Fortunately, the State of Washington, treated in this report, appears to be relatively free of serious reservoir-silting problems, although the available data are admittedly meager. These data are valuable, however, as part of a Nation-wide summary because they do indicate this relative freedom from silting troubles in reservoir operation and new construction in this area.

GENERAL INFORMATION

All of the quantitative data on reservoir sedimentation in this report were obtained by the late William T. Holland of the Sedimentation Section, Soil Conservation Service, while making a reconnaissance inspection of reservoirs of this State during May, June, and July 1936. The data on the silting basin at Wilsoncreek were obtained by a detailed engineering survey made by the Sedimentation Section of the Soil Conservation Service (page 11). All other information was obtained from scattered published and unpublished sources.

No detailed reservoir surveys to determine loss of storage capacity by silting have been made in Washington. The estimates of capacity losses given in this report are based on results obtained by reconnaissance sedimentation surveys. A reconnaissance-type survey consists of measuring the thickness of sediment at a few well-distributed locations in the reservoir and calculating from these measurements the ratio of sediment volume to the original storage capacity of the reservoir. Surveys of this type have been made by the Sedimentation Section of the Soil Conservation Service on several hundred reservoirs throughout the country to provide data satisfactory for estimating the general order of magnitude of reservoir silting. These data are not comparable in accuracy to those obtained from detailed surveys and are not intended for use in making close comparisons of rates of accumulation or erosion from watershed areas. They are sufficiently reliable, however, to indicate whether the useful life of the reservoir is of the order of tens or scores or hundreds of years. In reviewing the results of the reconnaissance sedimentation surveys in Washington, it appears that there is a general absence of measurements of the thickness of delta deposits of coarse material at the upper ends of the lakes; and since delta deposits often represent a sizable percentage of the incoming sediment load, especially in this State, it is believed that the estimated rates given in this report are minimum rates and are generally lower than the actual rates of silting.

The exact number of dams and storage reservoirs in the State of Washington is not known, but the Soil Conservation Service has assembled detailed information on more than 100. The total cost of construction of all reservoirs in the State, with appurtenant works, is estimated to be more than $378,000,000.[1] This represents a tremendous investment which is probably as great as, if not greater than, that in any other State in the Nation. More than one-half of this investment, however, is represented in the cost of the Bonneville and Grand Coulee projects. The total investment in the State, exclusive of Bonneville and Grand Coulee projects, has been more than $160,000,000, of which 79 percent has been for power development, 8 percent for irrigation, 7 percent for water-supply purposes, and 6 percent for flood control. Less than 1 percent has been invested for other purposes, including recreation.

Although the data contained in this report are confined to less than 25 percent of the reservoirs in the State, these data, nevertheless, give a general indication of the extent of reservoir silting in the several main drainage basins of Washington.

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[1] This estimate, as well as the cost analyses on the following pages, is based on available information and, in general, does not include the cost of a number of small developments in different sections of the State upon which no information is available.

The reservoir and silting data are discussed according to the principal drainage basins in Washington. The discussion for each basin includes an estimate of the cost of dams and reservoirs in the basin according to purpose served; a summary of silting data pertaining to the major reservoir projects in the basin; a summary of other sedimentation data which have a definite relationship to reservoir silting; and a conclusion of the probable extent of reservoir silting in the basin. Figure 1 shows the location of each principal drainage basin and the reservoirs on which sedimentation studies have been made. Table 1 is a summary of all the known suspended-load data obtained in the State. Tables 2, 3, and 4 give engineering, watershed, and silting data for selected dams and reservoirs in Washington.

WASHINGTON COAST BASIN

More than $7,900,000 has been spent for dam and reservoir construction in the Washington Coast Basin. This is estimated to be about 5 percent of the total cost of all such projects in the State of Washington, exclusive of the Bonneville and Grand Coulee developments. It is estimated that out of this $7,900,000, 17 percent has been spent on water-supply projects and 82 percent for power development. The Elwha and Glines Canyon power developments, near Port Angeles, are the only major projects in the Washington Coast Basin.

No silting data are available on these reservoirs or any minor reservoirs located in this drainage basin. Several areas of severe sheet erosion and frequent gullies are known to exist in the Washington Coast Basin, and reservoirs of relatively low capacity-watershed ratio[2/] located downstream from these areas might be filling with sediment rapidly.

[2/] The capacity-watershed ratio, which is usually expressed in acre-feet of storage capacity per square mile of direct tributary drainage area, has been found to be one of the most important factors, generally, governing the rate of silting or annual loss of storage. With all factors affecting the rate of erosion in the drainage area being equal, the larger the watershed for any given size reservoir the greater will be the amount of sediment brought in and the higher will be the rate of capacity loss.

PUGET SOUND BASIN

Nearly $65,000,000 has been expended for dam and reservoir construction in the Puget Sound Basin. This amount is equal to more than 40 percent of the total investment for dams and reservoirs in the State, exclusive of Bonneville and Grand Coulee projects. About $48,000,000, or 74 percent, of this has been spent for power development, while approximately $8,000,000, or 12 percent, has been spent for water supply, and the same amount for flood-control purposes.

Major projects in this basin include Cushman No. 1 and Cushman No. 2 dams on the North Fork of the Skokomish River, Diablo and Ross dams on the Skagit River, Shannon dam on the Baker River, Electron power plant on the Puyallup River, LaGrande power plant on the Nisqually River, and White River power plant on the White River. Two large storage reservoirs, LaGrande and Alder, are at present under construction on the Nisqually River, and Mud Mountain flood-control dam is under construction on the White River.

The owners of Cushman No. 1 and Cushman No. 2 dams, in the western part of the basin, consider silting to be very slight in their reservoirs. This is to be expected in view of the fact that Cushman No. 1 was formerly a natural lake with an extremely high ratio of storage to drainage area and, in addition, has a very well-forested watershed. Cushman No. 2 is protected against silting by Cushman No. 1, immediately upstream. A small amount of material is picked up from the gorge of the spillway channel of Cushman No. 1 and carried into Cushman No. 2, but the amount of sediment derived from this source is considered negligible.

A reconnaissance sedimentation survey of Diablo Reservoir, in the northeastern part of the Puget Sound Basin, revealed that a very low rate of silting exists at this reservoir. Most of the sediment deposited in Diablo Reservoir consists of glacial silt carried in by Thunder Creek. Below Diablo Reservoir, however, the Skagit River is seriously eroding its banks, and any reservoir with a low capacity-watershed ratio constructed on the main stem in the lower reaches of this stream might have a much higher silting rate than that of Diablo Reservoir.

A definite sediment problem exists at the several large power developments located on the Nisqually, Puyallup, and White Rivers in the eastern part of the basin, although this problem is not directly connected with depletion of reservoir storage capacity. The Nisqually, Puyallup, and White Rivers are glacial-fed streams which, during flood periods, carry large quantities of silt, sand and gravel derived from the slopes of Mount Rainier. These flood periods occur when the melting of glaciers is most active, generally during the months of June, July, and August, and occasionally during the fall when the Chinook winds are common.

The power plants, in all cases, are located some distance from the points of diversion on the main streams, and water is brought to the regulating reservoirs or forebays by means of canals and flumes. Sediment carried by floods is deposited in the impounding areas above the diversion dams and in the flumes, canals, forebays and regulating reservoirs connected with the power plants. Furthermore, sediment in the water abrades the turbine linings, runners, wickets, and other parts of the turbines. It has been necessary to install sediment-control devices at these plants in order to overcome these problems.

The Puget Sound Power and Light Company has had considerable trouble with sediment at its Electron plant 20 miles southeast of Tacoma. This development consists of a diversion dam on the Puyallup River, 9 miles southeast of Kapowsin, Washington, and an equalizing reservoir and powerhouse 3 miles southeast of Kapowsin. A 10-mile wooden flume carries the water from the diversion dam to the equalizing reservoir. According to Seigfried (8)[3] sand is carried through the entire length of the flume and deposited in the equalizing reservoir, and an 8-inch motor-driven suction dredge is required to remove it from this reservoir recurrently. He estimated that about 225 cubic yards of sediment are removed from the equalizing reservoir each year, and that at least one-half as much or more is discharged annually through the nozzles of the impulse wheels.

The City of Tacoma has also experienced difficulty in connection with its power plant located on the Nisqually River, 30 miles south of Tacoma. This development consists of a concrete diversion dam on the Nisqually River, an 800-foot settling channel between the intake at the dam and the portal of a 2-mile tunnel which crosses the neck of a loop in the river to a forebay from which penstocks lead to the turbo-generators 415 feet below. The diversion dam, which is 50 feet high and 260 feet long, forms a pond with an area of 37 acres and a normal capacity of 172 acre-feet. Coarse sediment brought down by the river during floods is dropped in the pond behind the diversion dam. The dam is provided with sluice-gates, and, periodically, at low stages of the river, 150,000 cubic yards of sediment are flushed through the dam (4). The settling channel is also provided with sluice-gates at its lower end to permit flushing the accumulated sediment out into the river below the dam. The settling channel can accomodate up to 7 feet of sediment, but during flood periods it is necessary to sluice out as much as some 2,000 cubic yards daily (1). The regulating reservoir above the penstocks is also provided with sluice-gates to permit annual flushing of the final deposits of sediment which are dropped before the water enters the penstocks. The maximum thickness of sediment in this reservoir is often 7 feet and averages 3 or 4 feet at the end of a year.

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[3] Refers to literature cited, see page 14.

The Puget Sound Power and Light Company found it necessary to install settling basins at its White River plant 12 miles east of Tacoma. Water for this development is diverted from the White River near Buckley, Washington, and carried by flume to a chain of settling basins and thence by canal to Lake Tapps, the storage basin, which is 8 miles from the point of diversion. The powerhouse is located below Lake Tapps. The chain of settling basins is about 2 miles long and the basins are provided with sluice-gates to permit sluicing out the accumulated sediment and prevent it from being transported into Lake Tapps.

Conditions conducive to high reservoir-silting rates are found especially on the Puyallup River and its major tributaries. According to the U. S. Army Engineers (11), the storage capacity of a reservoir located on the Puyallup River or its tributaries will be greatly reduced in a comparatively short time by sedimentation. They point out that the maximum suspended load probably reaches 10 percent by weight and probably is seldom less than 2 percent. They call attention to the fact that a series of soundings in the Puyallup waterway at Tacoma following several violent freshets in November 1909, revealed in excess of 1,000,000 cubic yards of sediment, most of which was brought down and deposited during the one month of November.

From these observations, it is probable that sedimentation in storage reservoirs constructed on streams that have their sources in the glaciers on the western slopes of the Cascade Mountains, especially in the vicinity of Tacoma, will be rapid. Silting rates are believed to be low in other sections of this drainage basin, especially where storage is developed in reservoirs or raised lakes which have a high capacity-drainage area ratio and where the watersheds are well forested.

The new Alder Dam, which is under construction by the City of Tacoma on the Nisqually River, will create a reservoir in which most of the sediment coming down this stream will deposit, but because of a high ratio of capacity to drainage area (more than 500 acre-feet per square mile) it is expected that the rate of capacity loss will be low.

The smaller LaGrande Dam, which is under construction also by the City of Tacoma, is located just below the Alder Dam on the same stream, and will be protected against a high rate of silting by the Alder Dam. The Mud Mountain flood-control dam, which is under construction on the White River, has a high capacity-watershed ratio, and the orifices of this dam will remain open permanently so that the reservoir will be empty at all times except during flood periods. Much of the sediment brought in, therefore, will be washed out, and serious sedimentation of this reservoir is not anticipated. Suspended-load measurements on the Cedar and Skagit Rivers indicate that generally the silting rates of reservoirs constructed on these streams will be low unless the capacity-wastershed ratio is very low.

LOWER COLUMBIA RIVER BASIN

Of the total expenditures for various dam and reservoir projects in Washington, exclusive of the Bonneville and Grand Coulee projects, only 5 percent, or a little over $8,600,000, has been spent in the Lower Columbia River Basin, and practically all of this has been for power development. Ariel Reservoir on the Lewis River is the only major development in this basin.

A reconnaissance sedimentation survey of Ariel Reservoir revealed a very low silting rate in comparison with rates found in other parts of the country. The low rate of sediment accumulation, amounting to 14.84 acre-feet per 100 square miles of drainage area, and the extremely high capacity-watershed ratio result in a very low rate of storage loss.

So far as can be determined, no suspended-load measurements have been made on streams in this area.

MIDDLE COLUMBIA RIVER BASIN

With the exception of the Bonneville project, located in this basin, the cost of dam and reservoir construction has probably not exceeded $4,000,000, or more than 2 percent of the total investment in the State, exclusive of the Bonneville and Grand Coulee projects. Two major reservoirs, in addition to Bonneville, are located in this basin. These are the Condit Reservoir for power development on the White Salmon River, and a flood-control reservoir on Mill Creek, a tributary of the Walla Walla River.

The rate of silting of Condit Reservoir, on the basis of measurements obtained by a reconnaissance sedimentation survey, was estimated to be 0.11 percent annually. Although this was the highest rate found in any reservoir in Washington, it is still considered low in comparison with rates found in several hundred other reservoirs in various parts of the United States. Despite a relatively high rate of silting, the sediment accumulation per 100 square miles of drainage is very low, which is a reflection of a very low capacity-watershed ratio, and the consequent passage of a large amount of sediment over and through the dam.

No information has been obtained on the probable rate of silting of Bonneville Reservoir. On the basis of turbidity measurements of the Columbia River, made by the City of Wenatchee, from January 1927 to November 1930, the U. S. Army Engineers (10) calculated the silt load during the maximum year of silt transportation to be only about 600 acre-feet, and concluded that silting of reservoirs constructed on this part of the Columbia River will be negligible.

Several streams in the Walla Walla River Basin carry large quantities of gravel, sand and silt during flood periods. An investigation of the Walla Walla Basin by the U. S. Department of Agriculture for flood-control purposes revealed that the impoundage areas above nine diversion dams for power, irrigation and water-supply purposes in this basin, were filled with silt, gravel and rocks, and no longer have any storage capacity.

A large flood-control reservoir is being constructed by the War Department to control floods on Mill Creek, a major tributary of the Walla Walla River, which also carries large quantities of sediment during flood periods. This reservoir will be located off-channel and a high rate of silting is not expected, inasmuch as a debris dam and stilling basin have been constructed above the diversion dam on Mill Creek.

Suspended-load measurements, covering a 2-year period, on the Columbia River at Cascade Locks indicate a low average sediment production per unit area of drainage. Although the total sediment load of the Columbia River is undoubtedly greater than indicated by these observations, because of the relatively large bed load transported by this stream, it is still apparent that reservoirs with moderate or high capacity-watershed ratio will have a low silting rate. Suspended-load measurements on the Klickitat River also indicate that high silting rates of reservoirs constructed on this stream need not be anticipated, provided that the capacity-watershed ratio is not too low.

UPPER COLUMBIA RIVER BASIN

The total cost of dam and reservoir construction in the Upper Columbia River Basin is estimated to be more than $240,000,000, including the cost of Grand Coulee, which alone is estimated to have cost nearly $178,000,000. The balance of more than $62,000,000 is nearly 40 percent of the total investment for dams and reservoirs in Washington, exclusive of Bonneville and Grand Coulee. Of this amount, 97 percent has been spent for power purposes, although the actual number of irrigation projects in this basin is greater than the number of power projects.

Major power developments, in addition to Grand Coulee Dam, include Lake Chelan on the Chelan River; Little Falls, Long Lake, and Nine Mile Falls, on the Spokane River; and Rock Island on the Columbia River. Large irrigation developments include Conconully on Salmon Creek, and Salmon Lake on Salmon Creek.

Lake Chelan, a raised natural glacial lake with an extremely high capacity-watershed ratio, obviously has no silting problem.

No actual sediment measurements have been made in the Little Falls Reservoir formed by the lowest of several dams on the Spokane River. Above Little Falls Reservoir is Long Lake and above this, Nine Mile Falls Reservoir. Still farther up stream is the Spokane Municipal Dam. The owners of Little Falls Dam believe that silting in their reservoir is very slight, which is to be expected since much of the normally small sediment load of the Spokane River would probably be intercepted by the upstream dams before it reaches Little Falls.

A reconnaissance sedimentation survey of Long Lake showed a very low rate of silting in this reservor, probably for the same reason.

A reconnaissance sedimentation survey was made of Nine Mile Reservoir, but the results of this investigation are considered questionable because of lack of satisfactory measurements.

The only sediment found behind the Rock Island Dam was some sand of the type normally transported in the Columbia River Channel. The Columia River is cutting its banks in places above the dam, and has carried some of the sand derived from this source into the reservoir.

So far as can be determined, no actual observations of silt conditions at Grand Coulee have been made. In reference to the sediment load of the Columbia River at Grand Coulee, John C. Page (5) states: "The water is practically free from silt. Impurities causing turbidity during part of the flood season are very fine, practically all carried in suspension, and will not be deposited in the reservoir."

A reconnaissance sedimentation survey of Conconully Reservoir on Salmon Creek indicated a very low rate of silting, due mainly to the well-forested condition of the watershed, which has practically no pasture or cultivated areas.

Sediment observations in nine small irrigation and power reservoirs in this drainage basin, in addition to those described above, revealed, in general, a very low rate of silting. The largest rate of silting was found in the Hunters Irrigation Reservoir on Hunters Creek near Hunter, Washington, which is losing storage at an estimated rate of 0.10 percent annually, the second highest rate in the State. The greater part of the sediment deposited in this particular reservoir apparently is derived from partially cleared hay land in the immediate vicinity of the reservoir.

The rapid silting of beaver dams in the Wenatchee River Basin has been noted (7). A local area of serious erosion and sedimentation developed in the Mission Creek drainage basin near Cashmere, Washington, as a result of overgrazing and logging, and in 1935 a dozen beavers were introduced to the upper waters of the stream to supplement a few which were already there and which were doing effective work in controlling soil and water losses. A survey of the area in 1937 revealed that the beavers had constructed a total of about 60 dams and most of these were silted full with a fine sandy

sediment. A detailed study of 22 of these showed that a total of 5,844 cubic yards of silt had been deposited behind the dams, the maximum deposit for a single dam being 707 cubic yards. This indicates that silting may represent a problem in small areas where natural forest conditions have been disturbed.

On the basis of sediment observations on 15 scattered large and small irrigation and power developments in the Upper Columbia River Basin, it is concluded that the rate of reservoir silting is generally very low in artificial reservoirs in this basin and, in most cases, does not form a serious problem unless the capacity-watershed ratio is low, or considerable cultivation and grazing exists in the drainage area. Suspended-load determinations on the Columbia, Spokane, and Wenatchee Rivers indicate that sediment production per unit area of drainage is low and consequently reservoir silting on these streams will be generally low.

SNAKE RIVER BASIN

The cost of construction of dam and reservoir projects in the Snake River Basin in Washington is believed to be less than 1 percent of the total cost of all such projects in the State. No major dams or reservoirs have been constructed in that part of the basin located within the State of Washington.

No information is available on silting conditions of reservoirs in the Snake River Basin. Since only minor dam construction, mostly for diversion purposes, has been undertaken in this basin, it is believed that silting of storage reservoirs is not a serious problem.

Suspended-load measurements on the South Fork of the Palouse River and tributaries indicate that sediment production per unit area is low to moderate. The rate of silting of reservoirs on these streams can be kept low only if reservoirs are constructed with a moderately high capacity-watershed ratio.

YAKIMA RIVER BASIN

Dam and reservoir construction in the Yakima River Basin has amounted to $7\frac{1}{2}$ percent of the total cost in the State, exclusive of the Bonneville and Grand Coulee projects. The total cost of construction in this region has been about $12,000,000, of which 86 percent has been for irrigation purposes, 13 percent for power, and 1 percent for other purposes. Major projects, all for irrigation, include Cle Elum on the Cle Elum River, Keechelas at Lake Keechelas, Kachess on the Kachess River, and Tieton on the Tieton River.

A reconnaissance sedimentation survey of Tieton Reservoir revealed that the estimated average annual rate of silting, 0.04 percent, is very low, although the estimated sediment accumulation per unit area of drainage of 45.99 acre-feet per square mile is the highest of any found in the State of Washington. In comparison with rates found in other sections of the United States, this rate of sediment accumulation per unit of drainage would be considered as moderate. Because the ratio of storage to drainage area is extremely high, the average annual storage loss is very low. It is believed that most of the sediment in this reservoir is brought in by streams emptying directly into the reservoir from the south.

Owners of several smaller irrigation reservoirs in this basin report that they consider silting in these to be very slight.

A reconnaissance sedimentation survey of one of the major irrigation reservoirs in this region, general information relative to several smaller representative irrigation reservoirs, and suspended-load determinations of the Yakima River at Cle Elum and Prosser, all indicate that reservoir silting is probably not a serious problem in this region. The watersheds above most of the reservoirs are usually well-forested, and serious soil erosion is not widespread.

COULEE REGION

The estimated cost of reservoir construction in this region is less than 1 percent of that for the entire State, exclusive of the Bonneville and Grand Coulee projects. The only large irrigation development in this region is Moses Lake, which is a natural lake, raised by an 8-foot earth dam, owned by the Moses Lake Irrigation District.

The peculiar physical characteristics of the Coulee Region, which are not found anywhere else in the United States, lend themselves to the development of unique irrigation and silting basins for agricultural purposes. These are constructed in the steep-sided Pleistocene glacial channels or so-called "coulees" of this region. The usual practice is to build a dam across the valley and impound the snow runoff for about 2 weeks in the spring to saturate the soil. The water is then drained off and the soil cultivated. Most of the sediment in the water is deposited during this period and adds to the fertility of the loam deposits of the coulee bottoms.

A detailed survey of the Bennett Basin near Wilsoncreek, Washington, which is a typical irrigation and silting basin, was made by the Sedimentation Section of the Soil Conservation Service in September 1936 (3). It was found that in 19 years of operation, an average depth of about 1.4 feet of sediment, equal to a total volume of 470 acre-feet of sediment, had been deposited above the dam. The principal source of sediment is the highly erodible loess-covered uplands which extend over more than half of the entire watershed area.

Since the only large storage development in Coulee Region was formerly a natural lake with an extremely high ratio of storage to drainage area, silting of major storage reservoirs is not a problem in this basin. Sediment carried by a number of streams in the Coulee Region is purposely stopped behind dams but its deposition in these cases is considered beneficial and loss of unimportant storage behind these dams is expected.

CONCLUSIONS

Rates of reservoir silting are generally not very high in the State of Washington because one or more of the following conditions usually exist at nearly every major reservoir: (1) The reservoir is a raised natural lake; (2) the reservoir is off-channel, permitting a certain amount of sediment control; (3) the ratio of storage capacity to watershed area is high; or (4) the sediment production per unit area of drainage is low due to the well-forested condition of the watershed.

The highest rate of silting was found to occur in the Condit Reservoir on the White Salmon River in Middle Columbia River Basin. This relatively high rate was due to a low capacity-watershed ratio rather than to a high rate of erosion in the watershed.

The highest annual rate of sediment production per unit area of drainage in the State, as determined by suspended-load measurements, was found to be a moderate rate of 62.4 acre-feet per 100 square miles, occurring on the watershed of Missouri Flat Creek, a tributary of the South Fork of the Palouse River. The highest rate of sediment production per unit area of drainage, as determined by reservoir deposits, was found above the Tieton Reservoir on the Tieton River in the Yakima River Basin, but because of the extremely high capacity-watershed ratio, the rate of silting is very low.

A summary of existing suspended-load data for streams in Washington (table 1) indicates that the average sediment production per unit of drainage area is generally very low in the State of Washington when compared with rates found in other parts of the United States.

Large quantities of sediment are carried by certain streams in some parts of the State, notably by streams of glacial origin on the western slopes of the Cascade Mountains in the Puget Sound Basin and by streams flowing across the Coulee Region. Sediment-control measures have been incorporated in the designs of the major projects located on the Cascade streams, and difficulties due to sedimentation have been largely overcome, although at considerable cost both for installation and operation. In the Coulee Region the sediment is trapped and used for agricultural purposes and is, therefore, not considered detrimental.

In various parts of the State, serious soil erosion exists, but, so far as is known, the contribution of sediment from these areas has not resulted in high silting rates in existing major reservoirs, few of which are located below such areas of erosion. In general, when compared with silting rates found in other sections of the United States, the average rate of silting of Washington reservoirs is very low.

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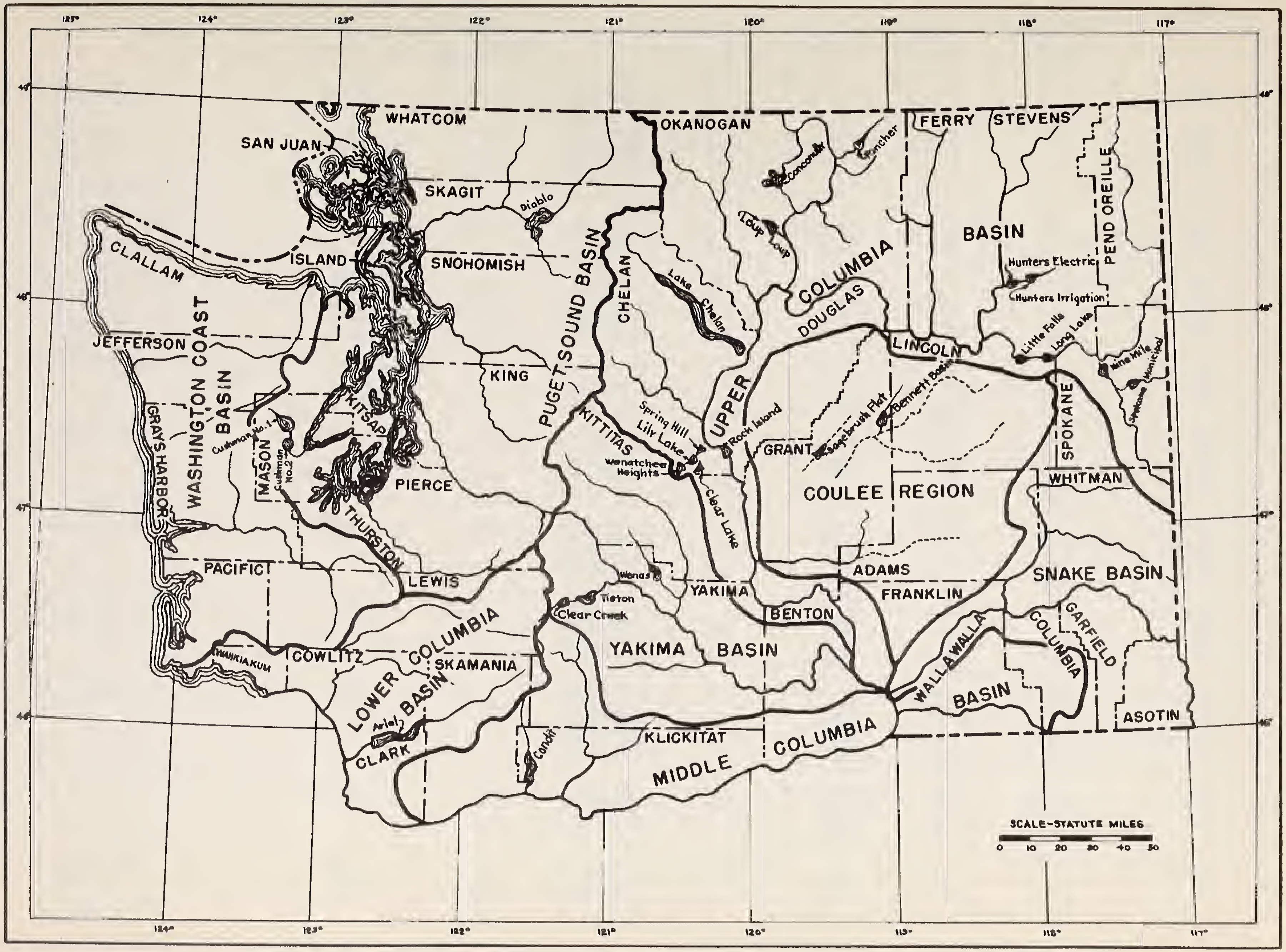

Figure 1—Reservoirs in Washington on which sedimentation studies have been made.

Table 1.--Suspended-load data for principal drainage basins in Washington

Stream	Station	Drainage area	Period	Mean suspended matter	Suspended matter during period	Annual suspended matter[1]	Annual sediment per 100 square miles of drainage	Reference number
		Square miles		Ppm	Tons	Acre-feet	Acre-feet	
Washington Coast Basin								
Chehalis River	Centralia	---	2/1/10-1/31/11	18	---	---	---	(12)
Wynoochee River	Montesano	---	7/17/10-8/19/10	1.6	---	---	---	(12)
Puget Sound Basin								
Cedar River	Ravensdale	149	2/1/10-1/31/11	4.2	2,960	2.3	1.5	(12)
Green River	Hot Springs	---	2/1/10-8/10/10	7.0	---	---	---	(12)
Skagit River	Sedro Woolley	2,930	2/1/10-1/31/11	19	363,550	278.2	9.5	(12)
Wood Creek	Everett	---	3/13/10-1/31/11	13	---	---	---	(12)
Lower Columbia River Basin								
None	---	---	---	---	---	---	---	---
Middle Columbia River Basin								
Columbia River	Cascade Locks	239,600	1/1/10-12/31/10	52	14,022,000	10,730.0	4.5	(12)
			8/11/11-8/14/12	40	7,000,000	5,356.6	2.2	(12)
Klickitat River	Klickitat	1,090	2/1/10-1/31/11	15	36,920	28.2	2.6	(12)
Upper Columbia River Basin								
Columbia River	Northport	---	2/1/10-1/31/11	4.7	---	---	---	(12)
Columbia River	Pasco	103,000	2/1/10-1/31/11	6.7	1,208,200	924.5	.9	(12)
Okanogan River	Okanogan	---	3/3/10-1/16/11	24	---	---	---	(12)
Salmon River	Malott	150	5/23/05-1/13/06	---	2,300	---	---	(9)
Spokane River	Spokane	4,000	2/1/10-1/31/11	4.1	45,900	35.1	.9	(12)
Wenatchee River	Cashmere	1,200	2/1/10-1/31/11	7.0	55,400	42.4	3.5	(12)
Snake River Basin								
Dry Fork of South Fork of Palouse River	Pullman	7.6	1/1/35-12/31/35	---	1,695	1.3	17.1	(2)
			1/1/36-12/31/36	---	4,214	3.2	42.4	(2)
			1/1/37-12/31/37	---	3,757	2.9	37.8	(2)
			1/1/38-6/30/38	---	1,231	---	---	(2)
Average annual					3,221	2.5	32.4	
Fourmile Creek	Shawnee	71.9	6/1/34-5/31/35	---	28,800	22.0	30.6	(6)
			6/1/35-5/31/36	---	52,972	40.5	56.3	(6)
			6/1/36-5/31/37	---	40,414	30.9	43.0	(6)
			6/1/37-5/31/38	---	24,258	18.6	25.9	(6)
			6/1/38-5/31/39	---	40,863	31.3	43.5	(6)
			6/1/39-5/31/40	---	53,587	41.0	57.0	(6)
Average annual					40,152	30.7	42.7	
Missouri Flat Creek	Pullman	27.5	6/1/34-5/31/35	---	9,825	7.5	27.3	(6)
			6/1/35-5/31/36	---	22,466	17.2	62.4	(6)
			6/1/36-5/31/37	---	17,153	13.1	47.7	(6)
			6/1/37-5/31/38	---	6,367	4.9	17.8	(6)
			6/1/38-5/31/39	---	15,615	11.9	43.4	(6)
			6/1/39-5/31/40	---	13,741	10.5	38.2	(6)
Average annual					14,195	10.9	39.5	
Palouse River	Hooper	2,210	5/22/05-10/8/05	---	2,400	---	---	(9)
Paradise Creek	Pullman	37.0	7/1/34-6/30/35	---	11,213	8.6	23.2	(2)
			7/1/35-6/30/36	---	12,109	9.3	25.0	(2)
			7/1/36-6/30/37	---	11,420	8.7	23.6	(2)
			7/1/37-6/30/38	---	6,166	4.7	12.7	(2)
Average annual					10,227	7.8	21.1	
Snake River	Burbank	109,000	3/13/10-1/31/11	52	5,049,000	3,863.6	3.5	(12)
South Fork Palouse River	Pullman	81.1	6/1/34-5/31/35	---	19,603	15.0	18.5	(6)
			6/1/35-5/31/36	---	36,468	27.9	34.4	(6)
			6/1/36-5/31/37	---	26,367	20.2	24.9	(6)
			6/1/37-5/31/38	---	12,766	9.8	12.0	(6)
			6/1/38-5/31/39	---	28,775	22.0	27.1	(6)
			6/1/39-5/31/40	---	20,533	15.7	19.4	(6)
Average annual					24,085	18.4	22.7	
South Fork Palouse River	Pullman	132	6/1/34-5/31/35	---	32,708	25.0	18.9	(2)
			6/1/35-5/31/36	---	57,190	43.8	33.1	(2)
			6/1/36-5/31/37	---	46,629	35.7	27.0	(2)
			6/1/37-5/31/38	---	20,963	16.0	12.1	(2)
Average annual					39,373	30.1	22.8	
Yakima River Basin								
Naches River	Naches	930	2/1/10-6/30/10	29	---	---	---	(12)
Yakima River	Cle Elum	500	2/1/10-1/31/11	5.8	18,336	14.0	2.9	(12)
Yakima River	Prosser	5,050	2/1/10-1/31/11	17	120,193	92.0	1.8	(12)
Coulee Region								
None	---	---	---	---	---	---	---	---

[1] Dry weight of a cubic foot of sediment assumed to be 60 pounds.

Table 2.--General data on selected dams and reservoirs in Washington

Name	County	Nearest city	Stream	Use[1]	Owner	Date completed	Type of dam[2]	Height	Length	Spillway elevation	Surface area	Total original capacity
								Feet	Feet	Feet	Acres	Acre-feet
Washington Coast Basin												
None	----------------	-------------------------	-------------------	----	--------------------------------	------	--	---	----	----------	------	-------
Puget Sound Basin												
Cushman No. 1	Mason	5 miles N.W. of Potlatch	N. Fk. Skokomish R.	P	City of Tacoma	1926	C	275	1,100	735	3,800	440,000
Cushman No. 2	Mason	3 miles N.W. of Potlatch	N. Fk. Skokomish R.	P	City of Tacoma	1930	C	240	330	476.2	100	7,000
Diablo	Whatcom	65 miles E. of Bellingham	Skagit R.	P	City of Seattle	1930	C	386	1,180	1,205	700	90,000
Lower Columbia River Basin												
Ariel	Cowlitz, Clark	12 miles N.E. of Woodland	Lewis R.	P	Inland Power and Light Co.	1931	C	313	1,250	235	3,836	394,000
Middle Columbia River Basin												
Condit	Klickitat	3 miles N. of Underwood	White Salmon R.	P	Northwestern Electric Co.	1913[3]	C	125	471	295	97	1,081
Upper Columbia River Basin												
Lake Chelan	Chelan	At Chelan	Chelan R.	P	Chelan Electric Co.	1927	C	39	490	1,100	32,000	672,000
Clear Lake	Chelan	9 miles S. of Wenatchee	Stemilt Cr.	I	Lake Irrigation Co.	1905	E	10	-----	3,000	10	180
Conconully	Okanogan	16 miles N.W. of Okanogan	Salmon Cr.	I	U.S. Bureau of Reclamation	1909	E	67	1,000	2,287	460	14,400
Fancher	Okanogan	15 miles N.E. of Tonasket	Mill Cr.	I	Robert M. Fancher	1928	E	60	-----	4,300	25	400
Hunters Electric	Stevens	3 miles W. of Hunters	Hunter Cr.	P	Hunters Electric Light and Power Co.	1924	C	30	300	1,450	6	Small
Hunters Irrigation	Stevens	3 miles E. of Hunters	Hunter Cr.	I	Hunters Land Co.	1920	E	54	-----	1,554	35	322
Lily Lake	Chelan	9 miles S. of Wenatchee	Stemilt Cr.	I	Stemilt Irrigation Co.	1892	E	25	-----	3,200	18	350
Little Falls	Lincoln, Stevens	27 miles N.W. of Spokane	Spokane R.	P	Washington Water Power Co.	1910	C	59	-----	1,356	187	4,250
Long Lake	Lincoln, Stevens	24 miles N.W. of Spokane	Spokane R.	P	Washington Water Power Co.	1915	C	208	-----	1,531	4,830	229,000
Loup Loup	Okanogan	10 miles S.W. of Okanogan	Loup Loup Cr.	I	Boston Okanogan Orchards Co.	1923	E	50	-----	2,500	20	600
Nine Mile	Spokane	10 miles N.W. of Spokane	Spokane R.	P	Washington Water Power Co.	1908	C	60	-----	1,602.5	320	5,200
Rock Island	Chelan, Douglas	12 miles S.E. of Wenatchee	Columbia R.	P	Puget Sound Power and Light Co.	1931	C	119	4,400	581.5	3,300	10,000
Spokane Municipal	Spokane	5 miles E. of Spokane	Spokane R.	P[4]	City of Spokane	1894	TC	20	200	1,912	------	-------
Spring Hill (Wheeler)	Chelan	8½ miles S. of Wenatchee	Stemilt Cr.	I	Spring Hill Irrigation District	1888[5]	E	30	1,000	3,500	30	300
Wenatchee Heights	Chelan	10 miles S. of Wenatchee	Squilchuck Cr.	I	Wenatchee Heights Reclamation District	1922	E	72	-----	5,500	50	500
Snake River Basin												
None	----------------	-------------------------	-------------------	----	--------------------------------	------	--	---	----	----------	------	-------
Yakima River Basin												
Clear Creek	Yakima	38 miles W. of Yakima	Tieton R.	I	U. S. Bureau of Reclamation	1914[6]	C	84	404	3,015	270	5,800
Tieton	Yakima	30 miles W. of Yakima	N. Fk. Tieton R.	I	U. S. Bureau of Reclamation	1925	E	222	905	2,926	2,500	202,500
Wenas	Yakima	16 miles N.W. of Yakima	Wenas Cr.	I	Wenas Irrigation District	1926[7]	E	50	350	1,900	160	1,100
Coulee Region												
Bennett Basin	Grant	3 miles N.E. of Wilson-creek	Wilson Cr.	I	T. Claud Bennett	1918	E	30	925	1,390.30	345	2,903
Sagebrush Flat	Douglas	14 miles N.W. of Ephrata	Sagebrush Flat	I	W. E. Southard	1926	E	{18, 10	{300, 500	----------	162	-------

1P - Power, I - Irrigation.
2C - Concrete, E - Earthfill, TC - Timber Crib.
3Raised 5' in 1927.
4Originally used for water-supply purposes.
5Raised 7' in 1924.
6Raised 25' in 1918.
7Raised 5' in 1929.

Table 3.--Data on watershed characteristics of selected reservoirs in Washington

Name	Watershed area	Topography and elevations	Soils	Estimated land use				
				Forest	Meadow or pasture	Cultivated	Grazing	Idle
	Square miles			Percent	Percent	Percent	Percent	Percent
Washington Coast Basin								
None	-----	----------	----------	---	---	---	---	---
Puget Sound Basin								
Cushman No. 1	90	Mountainous with steep slopes, elevations to 6,400'	Loams, gravelly loamy sands, and stony sandy loams	90	---	---	---	---
Cushman No. 2	96	Mountainous with steep slopes, elevations to 6,400'	Loams, gravelly loamy sands, and stony sandy loams	90	---	---	---	---
Diablo	1,200	Mountainous with steep slopes, elevations to 9,000'	Gravelly sandy loams	100	---	---	---	---
Lower Columbia River Basin								
Ariel	733	Mountainous, elevations to 12,300' - (Mt. Adams)	Mostly rough and stony land, with some clay loam	95	3	2	---	---
Middle Columbia River Basin								
Condit	337	Mountainous, elevations to 12,300' - (Mt. Adams)	Mostly rough and stony land, with some clay loam	85	10	5	---	---
Upper Columbia River Basin								
Lake Chelan	950	Mountainous, elevations to 9,500'	Rough and stony land, granite soils	90	10	---	---	---
Clear Lake	11	Mountainous, elevations to 6,800'	Mostly rough and stony land, with some loam	90	25	---	---	---
Conconully	121	Mountainous, elevations to 8,200'	Mostly rough and stony land	85	---	---	---	---
Fancher	10	Mountainous, elevations to 7,200'	----------	50	30	30	---	---
Hunters Electric	25	Rolling to hilly and mountainous	Rough and stony land, glacial drift in valleys	70	90	15	---	---
Hunters Irrigation	25	Rolling to hilly and mountainous	Rough and stony land, glacial drift in valleys	70	90	10	---	---
Lily Lake	11	Mountainous, elevations to 6,800'	Mostly rough and stony land, with some loam	90	25	---	---	---
Little Falls	5,868	Gently rolling, elevations to 5,400'	Sandy gravelly loams and silt loams	10	50	20	---	10
Long Lake	5,124	Gently rolling, elevations to 5,400'	Sandy gravelly loams and silt loams	10	50	30	---	10
Loup Loup	20	Mountainous, elevations to 7,400'	----------	70	---	---	---	---
Nine Mile	5,400	Gently rolling, elevations to 5,400'	Sandy gravelly loams and silt loams	10	50	20	---	10
Rock Island	(1)--	(1)----------	(1)----------	(1)	(1)	(1)	(1)	(1)
Spokane Municipal	4,464	Gently rolling, elevations to 5,000'	Sandy and silt loams	12	45	15	---	10
Spring Hill (Wheeler)	4	Mountainous, elevations to 6,800'	Mostly rough and stony land, with some loam	90	25	---	---	---
Wenatchee Heights	10	Mountainous, elevations to 6,800'	Mostly rough and stony land, with some loam	90	25	---	---	---
Snake River Basin								
None	-----	----------	----------	---	---	---	---	---
Yakima River Basin								
Clear Creek	60	Mountainous, elevations to 7,300'	Rough and stony land. Shallow soils on south slopes	95	---	---	20	---
Tieton	187	Mountainous, elevations to 7,300'	Rough and stony land. Shallow soils on south slopes	95	5	---	20	---
Wenas	113	Mountainous, elevations to 6,000'	Porous loamy soil. Shallow soils on south slopes	67	33	10	---	---
Coulee Region								
Bennett Basin	475	Channel scabland and loess-covered uplands, elevations to 2,600'	Fine sandy loams, very fine sandy loams, and silt loams	---	---	60	---	---
Sagebrush Flat	100	Channel scabland and loess-covered uplands	Fine sandy loams	---	80	20	---	---

[1]Watershed area extremely large, covering nearly a quarter of the entire State. Includes several distinctive physiographic provinces with many different climatic, soil and land use conditions.

Table 4.--Data on silting of selected reservoirs in Washington

Name	Date of observation	Number of sediment measurements	Maximum sediment depth found[1]	Location of maximum sediment depth	Estimated sediment volume	Estimated storage loss	Estimated annual storage loss	Estimated annual sediment accumulation per 100 sq. mi. of drainage	Original storage per sq. mi. of drainage	Remarks
			Feet		Acre-feet	Percent	Percent	Acre-feet	Acre-feet	
Washington Coast Basin										
None	----------	--	----	----------	----	----	----	----	----	----------
Puget Sound Basin										
Cushman No. 1	7/15/36	--	----	----------	----	----	----	----	4,888.89	Originally a natural lake. Owners consider silting to be very slight.
Cushman No. 2	7/15/36	--	----	----------	----	----	----	----	72.92	Owners believe that silting is very slight.
Diablo	7/19-20/36	36	1.3	3/4 mile from head of Thunder Creek	358	0.40	0.07	4.97	75.00	----------
Lower Columbia River Basin										
Ariel	5/14/36	35	1.9	4,500' from Yale Bridge	544	.14	.03	14.84	537.52	----------
Middle Columbia River Basin										
Condit	5/13/36	19	5.6	In channel, 1,000' above dam	27	2.54	.11	.36	3.21	----------
Upper Columbia River Basin										
Lake Chelan	6/22/36	--	----	----------	----	----	----	----	707.37	Raised natural glacial lake. No silting problem exists.
Clear Lake	6/18/36	--	----	----------	----	----	----	----	4.00	Off-channel. Very little evidence of silting in diversion ditch. Owners consider silting to be very slight.
Conconully	6/21/36	21	.5	500' above dam	74	.51	.02	2.35	119.01	----------
Fancher	6/25/36	13	.6	In channel, 75' above dam	2	.58	.07	2.50	40.00	----------
Hunters Electric	7/4/36	--	----	----------	----	----	----	----	----	Owners consider silting to be very slight.
Hunters Irrigation	7/4/36	15	3.1	50' from west end of dam	5	1.53	.10	1.33	12.88	----------
Lily Lake	6/18/36	--	----	----------	----	----	----	----	7.78	No marginal evidences of silting around the shores of lake. Owners consider silting to be very slight.
Little Falls	6/4/36	--	----	----------	----	----	----	----	.72	Owners consider silting to be very slight.
Long Lake	6/4/36	36	1.5	1,500' above dam	1,314	.57	.03	1.22	44.69	----------
Loup Loup	6/20/36	--	----	----------	----	----	----	----	30.00	Owners consider silting to be very slight.
Nine Mile	6/3/36	24	1.5	In channel, 1-3/4 miles above dam	43	.83	.03	.03	.96	Data on silting questionable.
Rock Island	6/12/36	--	----	----------	----	----	----	----	----	No sedimentation evident behind dam other than deposition of some sand normally contained in the Columbia River channel.
Spokane	6/5/36	--	----	----------	----	----	----	----	----	Owners consider silting to be very slight.
Spring Hill (Wheeler)	6/18/36	15	.04	1,800' from north bank	1	.43	.01	.56	4.00	Off-channel.
Wenatchee Heights	6/17/36	15	.03	1,500' from east end of lake	1	.24	.02	.77	2.50	----------
Snake River Basin										
None	----------	--	----	----------	----	----	----	----	----	----------
Yakima River Basin										
Clear Creek	5/15/36	--	----	----------	----	----	----	----	96.67	Owners feel that very little silting has occurred in this reservoir.
Tieton	5/16/36	22	2.2	In channel, 1,000' above dam	946	.47	.04	45.99	1,082.89	----------
Wenas	5/15/36	--	----	----------	----	----	----	----	24.44	Reservoir emptied every fall but silting has not been noticable to the owners.
Coulee Region										
Bennett Basin	8/17-9/17/36	--	4	In center of basin	470	----	----	----	15.00	----------
Sagebrush Flat	6/10/36	--	1.5	----------	----	----	----	----	----	An average of approximately 1 inch of sediment added annually.

[1] Generally in lower part of lake exclusive of delta deposits.